DATA ANALYSIS OF THE LOOP MARINE AND ESTUARINE MONITORING PROGRAM, 1978-95

TECHNICAL INFORMATION FOR THE LOOP MARINE AND ESTUARINE MONITORING PROGRAM REVISION

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TECHNICAL INFORMATION FOR THE LOOP MARINE AND ESTUARINE MONITORING PROGRAM REVISION

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INTRODUCTION

Louisiana Offshore Oil Port

The Louisiana Offshore Oil Port (LOOP) facilities in coastal Louisiana provide the United States with the country's only superport for off-loading deep draft tankers. The facilities are located in Lafourche Parish in southeast Louisiana, south of New Orleans; and in adjacent offshore waters west of the Mississippi River Delta. The development is operated by LOOP LLC., a private corporation owned by Shell Oil Company, Texaco Inc., Ashland Inc., Murphy Oil Corporation, and Marathon Pipeline Company.

LOOP INC., (later restructured as LOOP LLC.) was organized in 1972 as a consortium of companies to design, construct and operate a deepwater port on the Louisiana coast. Pre-permit baseline studies related to the proposed development were conducted from 1972 to 1975. Major documents related to these studies are listed in Table 1. State and federal licenses to own and operate a deepwater port were issued in January 1977, and accepted on August 1 1977. The state license was issued to LOOP pursuant to the Louisiana Offshore Terminal Act (LA R.S. 34:3101 et seq.). A federal *License to Own, Construct and Operate a Deepwater Port* was issued to LOOP by the U.S. Department of Transportation (USDOT) pursuant to the federal Deepwater Ports Act (33 U.S.C. 1501, et seq.). The first oil tanker was offloaded on May 5, 1981.

Facility Description

The superport complex consists of an offshore marine terminal located about 30 km from the mainland in the Gulf of Mexico, an onshore storage facility at the Clovelly salt dome near Galliano about 50 km inland from the coast, and a large diameter pipeline system including a pumping booster station onshore near Fourchon to deliver oil to the storage facility. The pipeline system also connects the Clovelly salt dome oil storage facility to transportation facilities on the Mississippi River. A large brine storage reservoir (101 ha) is positioned near the Clovelly dome storage facilities. A small-boat harbor and logistics facility is located at Port Fourchon, on Bayou Lafourche. Location maps are provided in each data analysis volume.

Table 1. List of reports produced for superport planning (after Sasser et al. 1982).

Year	Title	Comment
1972	LOOP feasibility study	LOOP's Engineering Feasibility Study
1972	A Superport for Louisiana	Superport Task Force Report
1972	LSU Superport Study #1	Requested by Superport Task Force
1972	LSU Superport Study #2	Requested by National Sea Grant Program
1973	LSU Superport Study #3	Requested by LOTA to formulate EPP
1973	LSU Superport Study #4	Requested by LOTA to formulate EPP
1974	Alternate Site Location Evaluation	Prepared by Dames and Moore for LOOP, Inc.
1976	Environmental Baseline Studies Vols. 1–4	Prepared by LSU for LOOP, Inc.
1976	Environmental Impact Study	US Department of Transportation

The marine terminal consists of three Single Point Mooring (SPM) structures connected by pipelines to a platform-mounted pumping station in the Gulf of Mexico, 30 km southeast of Belle Pass, Louisiana. Water depth at the platform is 36 m. From the offshore marine terminal facility, crude oil is pumped northward through a large diameter (56 inch) buried pipeline, through the onshore booster station at Fourchon, to the Clovelly salt dome storage complex near Galliano. The crude oil is stored in caverns constructed in subterranean salt domes. These storage chambers were formed by solution mining utilizing local surface water in the area. A second pipeline extends southward parallel to the oil pipeline and carries brine leached from the Clovelly storage facility to the diffuser disposal site located in open Gulf of Mexico waters approximately 4.8 km offshore and adjacent to the LOOP oil pipeline. Additional distributary pipelines move oil from the Clovelly complex to outlying pipelines and refining centers.

Project Area

The Barataria estuary and the offshore area where LOOP is located is an extremely diverse and complex natural system. It is located in the Mississippi River Deltaic Plain region. This region was formed and is continually influenced by processes associated with the deposition of massive amounts of sediments carried by the Mississippi River. The LOOP pipeline traverses the major wetland habitats in the Louisiana coastal area. The 159 km pipeline crosses the near-offshore Gulf of Mexico, beach/barrier headland, and estuary. Within the estuary, four salinity zones - saline, brackish, intermediate and fresh - are traversed, each providing a unique habitat supporting a variety of species.

The coastal marshes of Louisiana are among the most productive ecosystems in the world, supporting a wide variety of estuarine-dependent organisms. Louisiana leads fishery production within the northern Gulf of Mexico and is second only to Alaska among all states (NMFS 1997). Louisiana is the leader in the United States for the production of shrimp, blue crab, oyster, crawfish, tuna, red snapper, wild catfish, black drum, sea trout, and mullet (McKenzie et al. 1995). Ninety-five percent of the Louisiana fish and shellfish landings are estuarine-dependent species (McKenzie et al. 1995). The fish community of Barataria estuary is the most diverse of any estuary in Louisiana with 191 species from 68 families (Condrey et al. 1995).

Monitoring Program

In recognition of the potential for significant environmental impacts much attention was given to environmental safeguards by state and federal agencies and by the superport developers (see review by Sasser et al. 1982). Because of the potential risks associated with the construction and operation of the superport (e.g. bringing the world's largest oil tankers to one of the most productive fisheries resources in the world), both state and federal licenses required environmental monitoring of LOOP construction and operational activities. The environmental monitoring program (EMP) was developed under mandate of the Superport Environmental Protection Plan (revised, 1977), a regulation of the State of Louisiana implementing the Offshore Terminal Act. The EMP (section 3.1, page 8, March 1986) lists the objectives of the monitoring program as:

(1) to obtain seasonal environmental and ecological data so that conditions existing during operation can be related to historical baseline conditions;

(2) to detect during the operation of the project any adverse alterations or damages to the environment so that corrective action can be taken as soon as possible;

(3) to obtain sufficient data to determine the cause or causes of environmental damages or alterations so that responsibility can be properly placed; and

(4) to provide information in order to evaluate long and short-term impacts of the project.

Ecological components of the estuarine/marine monitoring program include: water chemistry, physical hydrography (including brine discharge), zooplankton / ichthyoplankton, demersal nekton, benthos, and sediment quality. The Louisiana Department of Wildlife and Fisheries collected the data related to these components from

In light of these considerations the following specific recommendations for each monitoring component (Water Chemistry, Physical Hydrography and Brine Monitoring, Zooplankton and Ichthyoplankton, Demersal Nekton, and Sediment Quality) assume the continuation of an environmental monitoring program based on about the same level of information acquisition as previously. The fact that we were able to detect a number of temporal trends and some impacts of LOOP operations indicates that the present monitoring program is responsive to the spirit of the EMP objectives. However, a number of changes are recommended to (1) increase the sensitivity of certain critical environmental variables to possible impacts; (2) make sampling more efficient, hence reducing costs; and (3) eliminate elements of the present monitoring program that appear to be insensitive to LOOP operations or are otherwise unnecessary.

WATER CHEMISTRY

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We have organized our recommendations into three basic categories:

(1) overall recommendations;

(2) specific sampling recommendations:

variables to be measured;

frequency and depth of sampling;

station distribution;

(3) other recommendations.

OVERALL RECOMMENDATIONS

•The monitoring program will be improved simply by extending the data base; in other words, the monitoring should be continued.

The long-term nature of the monitoring effort has numerous invaluable benefits for the State, LOOP, LLC., and the various agencies involved. The LOOP facility is unique to the lower 48 states, and is of unprecedented economic significance in terms of tonnage handled and its strategic economic positioning. It is located, however, directly in the middle of the finest and largest continental shelf fishing zones in the US. The water chemistry data sets we examined are useful for the intent of the monitoring program as identified in the original environmental management plan. The Superport is still operating and all significant impacts have probably not occurred (e.g., the unrealized large oil spill). The responsibilities for management have not diminished with time. Rather, these responsibilities have increased in the last 2 decades as our knowledge of how human use affects living resources has expanded.

The variability introduced by the Mississippi River is a significant complication of the analysis because of its size and proximity to the monitoring stations. A change in the measured parameter values between a before-and-after impact analysis may not be due to the potential impact factor (e.g., brine), but actually be the result of long-term trends or events in environmental factors unrelated to the LOOP facility use. Adequate monitoring of these long-term trends and events is required to determine responsibility for an impact (EMP Objective 3).

The large oil spill that occurred in April 1990 provided an opportunity to test for impacts from the anticipated much larger spill yet to occur (10X larger in 50 years, and up to 100X larger according to the EMP). There were significant differences in several important parameters immediately after the spill (chiefly phytoplankton pigments, sulfate and oxygen concentration) in the offshore zone. Tests of their statistical validity indicate that no similar results were found in the estuarine zone or with longer periods after the spill (up to 4 months later, for example).

The maximum 'credible oil spill' estimated in the original EIS was 240,000 barrels, which is 100 times larger than that spilt through 1996. It is based on a pre-project spill recurrence interval that is substantiated by experience since 1978, and which includes a total monthly spill of about 23,000 barrels. In other words, the recurrence interval graph of the original projections in the EIS and the subsequent events are nearly coincidental. Fortunately, this very large spill has not happened (yet). We were able to detect changes in water quality in the much smaller spill (about 1% of the predicted largest anticipated oil spill), which should raise concerns about the impacts of a large spill. These results and observations suggest that a credible monitoring program should take into account the information needs of this larger, yet unrealized oil spill.

•We recommend more frequent sampling be anticipated when a large spill occurs (sampling at more than 4 times/month) at the long-term monitoring stations.

Current speeds throughout the region suggest that water masses are replaced in days, not weeks or months. Events like a large (yet unobserved) oil spill similar to that predicted in the original environmental management plans, must be sampled within weeks of the event to establish reasonable baseline conditions against which to measure impacts (EMP Objective 1). If the region were homogeneous, not near the Mississippi River, etc., then baseline conditions might be more safely predicted from less frequent sampling (e.g., quarterly). A second, related issue, is that the monitoring program should be prepared to mobilize for a Mega-oil spill. The dispersal of surface water and oil will be spread far beyond the LOOP Superport vicinity, and probably spread westward (assuming that is the dominant current direction). However, below the surface, there may be effects spreading in different directions from that in the surface layer.

SPECIFIC SAMPLING RECOMMENDATIONS

Table 1 Summarizes the trend analysis and the impact analyses (BACI) from Task 2. This table presents the results (both significant and non-significant) for each of the water chemistry variables. The trends are presented for inshore and offshore environments for surface and bottom values, and the impacts are presented by impact type (construction, brine discharge, oil spills).

Variables to be measured

•We recommend sampling all present water quality variables except for Alkalinity, Calcium, Sulfate, Total Dissolved Solids, and Total Solids.

(1) Alkalinity: This variable shows very little spatial variation and no temporal trends. Therefore it is probably insensitive to any impacts.

(1) Calcium: This variable showed no temporal trends, and was not considered to be an important covariate, Therefore it is probably not useful in the determination of impacts.

(2) Sulfate: This variable is highly correlated with salinity (R=0.86 for surface values and R=0.84 for bottom values).

(3) Total Dissolved Solids This variable is highly correlated with salinity (R=0.97 for surface values and R=0.87 for bottom values).

(4) Total Solids: This variable is highly correlated with salinity (R=0.96 for surface and bottom values).

Frequency and depth of sampling

•We recommend monthly sampling of the water chemistry.

Temporal trends were calculated for two cases (1) using the monthly data, and (2) using the quarterly data. Trends were calculated for surface and bottom variables and for both the inshore and offshore environments. Using the monthly data, a total of 20 (8 inshore trends, 12 offshore) trends were detected. Using the quarterly samples, only 7 (2 inshore, 5 offshore) trends were detected. Clearly, quarterly sampling is not sufficient to detect the long-term trends needed to evaluate possible impacts of LOOP (EMP Objective 4).

Table 1. Summary of results (significant and non-significant) from Task 2 water chemistry analysis. Indicated for each water chemistry variable is the trend (positive, negative, not significant) for the inshore and offshore environment, whether an impact (presented by impact type, construction, brine discharge, oil spills) was significant or not significant, and an indication of whether or not a water chemistry variable is considered to be an important covariable. Trends are listed as significant if 70% or more stations in the environment (inshore or offshore) exhibited a statistically significant trend at the 0.05 level. Bold type trends indicate all stations exhibited a statistically significant trend.

I. Surface Variables

Variable	Temporal Trends Inshore	Temporal Trends Offshore	Impact Analysis (BACI) Const.	Impact Analysis (BACI) Brine	Impact Analysis (BACI) Clovelly Oil	Impact Analysis (BACI) Offshore Oil	Important Covariable
Alkalinity	No	No	na	na	na	na	No
Ammonia	No	No	No	No	Yes	Yes	Yes
Calcium	No	No	na	na	na	na	No
Chlorophyll-a	No	No	No	No	No	No	Yes
Nitrate-Nitrite	No	No	na	na	na	na	Yes
Oxygen	No	No	na	na	na	na	Yes
Phopshorus	No	No	na	na	na	na	Yes
Salinity	No	No	No	No	No	No	Yes
Silica	**Negative**	No	na	na	na	na	Yes
Sulfate	No	**Negative**	No	No	No	No	No
Suspended Solids	Negative	**Negative**	na	na	na	na	Yes
Total Dissolved Solids	No	No	na	na	na	na	No
Total Kjeldahl Nitrogen	**Positive**	**Positive**	No	No	No	No	Yes
Total Phosphorus	Positive	**Positive**	na	na	na	na	Yes
Total Solids	No	No	na	na	na	na	No
Turbidity	**Negative**	**Negative**	No	No	Yes	No	Yes

II. Bottom Variables

Variable	Temporal Trends Inshore	Temporal Trends Offshore	Impact Analysis (BACI) Const.	Impact Analysis (BACI) Brine	Impact Analysis (BACI) Clovelly Oil	Impact Analysis (BACI) Offshore Oil	Important Covariable
Alkalinity	No	Positive	na	na	na	na	No
Ammonia	No	No					Yes
Calcium	No	Positive	na	na	na	na	No
Chlorophyll-a	No	No					Yes
Nitrate-Nitrite	No	**Positive**	na	na	na	na	Yes
Oxygen	No	**Negative**	na	na	na	na	Yes
Phopshorus	No	No	na	na	na	na	Yes
Salinity	No	No					Yes
Silica	No	No	na	na	na	na	Yes
Sulfate	Negative	**Negative**					No
Suspended Solids	No	No	na	na	na	na	Yes
Total Dissolved Solids	No	No	na	na	na	na	No
Total Kjeldahl Nitrogen	**Positive**	**Positive**					Yes
Total Phosphorus	**Positive**	**Positive**	na	na	na	na	Yes
Total Solids	No	No	na	na	na	na	No
Turbidity	No	No					Yes

•We recommend surface sampling inshore, surface and bottom sampling offshore with occasional mid-depth samples to define important water column structure (*e.g.*, oxygen minimum layer, halocline).

Correlation analysis indicated a high degree of correlation (correlation coefficients of ~0.9 for 13 variable, >0.7 and <0.9 for 3 variables) between surface and bottom for all the inshore water chemistry variables.

The offshore variables had much lower correlation coefficients (only 2 variables had correlation coefficients >0.8; 9 variables had correlation coefficients <0.5) between surface and bottom.

The mid-depth data did not add much information because it did not define the structure of the water column. A possible modification to the mid-depth sampling would be to use this sample to identify major structures (*e.g.*, low oxygen layer) in the water column. This sample would only be collected when such structure is detected by profile sampling.

Station distribution

•The stations need to be distributed to cover the LOOP pipeline route, as well as other LOOP potential impact areas with sufficient impact and control stations in each area.

The general station distribution that we recommend has a total of 28 stations, and is described below. This distribution would have enough stations to monitor the LOOP pipeline, the Clovelly Dome, the brine diffuser, and the offshore terminal. The existing stations can be used in a majority of the cases. The actual number could be less since some of the Clovelly dome stations may also be part of the upper Barataria system pipeline route stations.

The station distribution should have two controls and two impact stations in the following inshore areas along the pipeline route:

(1) The upper portion of the Barataria Bay System (four station total)
(2) The middle portion of the Barataria Bay System (four station total)
(3) The lower portion of the Barataria Bay System (four station total)

Eighty-seven percent of the inshore oil spills occurred at the Clovelly salt dome site (Station #38). There are 24 stations with record lengths > or = 10 years, but only one at Clovelly (#38). Station 39 is within 1.5 km of #38 (WSW), #16 is within 2.5 km (WSW), and #464 is within 4 km (NE). At least one more impact station should be added at the Clovelly Dome and a second station added within 1.0 km of the Clovelly Dome, resulting in a total of 6 stations near the Clovelly dome.

The station distribution should have two controls and two impact stations in the following offshore areas:

(1) The brine diffuser (four station total)
(2) The offshore terminal (four station total)

Two controls at a point midway between the brine diffuser and the offshore terminal.

OTHER RECOMMENDATIONS

•The analysis of the water chemistry data should be integrated with the biological data sets, particularly with the benthic community analyses.

The benthic community is the logical analytical subject for competent investigation of impacts near the brine disposal, and for oil spills (past and present). The benthic community is subject to a probable enhancement around the diffuser, if results from other studies are appropriate for this site. The immediate area of the brine plume (about 4 km^2 for a 1+ ppt plume) sweeps over an area of 16 km^2. The plume orientation is very responsive to currents, and the plume may move between the stations without detection by the present sampling grid. The benthic community is exposed to chronic conditions and some animals will remain for weeks and months within this brine plume shadow. The benthic data were not analyzed as part of this analysis and requires, as far as we can tell, annotations to make it usable. This data should be analyzed by independent benthic ecologists to check on the implications of the results in this report, including: the possibility of a brine plume 'halo' or disturbance area around the brine diffuser; the impacts of the April 1990, oil spills, the presence of brine or oil spill chemical markers in sediments and appearing coincidentally in time or space with changes in the water chemistry, nekton and plankton; detection of long-term trends in the benthic data that may be explained by the regional influences of the Mississippi River.

•The data from the benthic sled (brine sled) could be improved by sampling sufficiently in the field to go in all directions until a baseline value is found in all directions, and the salinity contours closed.

The benthic (brine) sled surveys are an excellent addition to the monitoring, but the contouring is frequently incomplete.

The sled sampling by the State Department of Wildlife and Fisheries clearly located a brine plume whose position on the bottom moves among the stations, adding variability to the measured parameters, and perhaps compromising the results of the BACI sampling design. The variability in bottom salinity at station 473, for example (see Figure 15), probably reflects these movements among and between sampling locations. The BACI analysis cannot, a priori, determine if the plume is over a station or not and a nearby station may be an adequate control station in one month, but an impact station in another month. Fixed control and impact stations cannot be assigned, therefore.

Some sort of adaptive sampling scheme (network of vertical profiles, towed vehicle) to collect data on the 3-dimensional structure of the brine plume should be implemented if major brine discharges occur. This will supply data that can be used to more adequately determine any short-term impacts of brine discharge (EMP Objective 4) and to close the contour profiles outlining the plume in both horizontal and vertical directions.

•The area is accumulating sediments, so dated cores might be useful to investigate the halo, if present, around the plume, and to retrospectively determine impacts near the brine diffuser.

The water column turns over in a matter of days, because of currents. The sediments are also the best depository of information on the effects (if any) of a large oil spill (of presently experienced spill or future larger sized spill).

•It would be useful to explore ways to open up these efforts to serious scientific efforts, and to publish analyses of the data arising from them.

This monitoring program is an exceptionally valuable opportunity for science and management interests. It would be useful to explore ways to open up these efforts on an ongoing basis to provide data for other scientific efforts, and to publish analyses of the data arising from them.

PHYSICAL HYDROGRAPHY AND BRINE MONITORING

by

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PHYSICAL HYDROGRAPHY AND BRINE MONITORING COMPONENT

Following the discussion in Task 2, we subdivide the discussion of a revised sampling plan according to environmental region: offshore, nearshore, lower estuary and upper estuary.

SIGNIFICANT RESULTS

Table 1. Significant results from Task 2 Data Analysis

Variable of interest	Temporal trends	Covariables	Impacts
Offshore temperature (surface)	increasing (stations 52, 53, 54, 55)	salinity	none
Offshore temperature (bottom)	increasing (stations 52, 53, 55, 704, 706, 708)	salinity	none
Offshore salinity (bottom)	increasing (stations 706, 708)	temperature river discharge rainfall	none
Upper estuary temperature	increasing station 16	salinity	none
Upper estuary salinity	decreasing station 317	temperature river discharge rainfall	none

NON-SIGNIFICANT RESULTS

We are unable to hypothesize a scenario whereby LOOP activities will significantly influence water temperature. Neither are we able to hypothesize a scenario whereby LOOP activities will affect salinity with the exception of two processes: brine diffusion and alterations of estuarine flow patterns. We did not analyze the sled data collected during monitoring of the brine diffuser plumes for reasons stated in our report at the end of Task 1. Never-the-less, it was clear from those data sets that brine discharge did alter the salinities very close to the sea bed. The full extent and duration of this change, as well as its sensitivity to external parameters such as current, ambient stratification, bottom slope, and turbulent intensity, are unknown. Any changes to estuarine flow regimes which may have resulted from LOOP construction activities in the estuarine environment were not detected in the analyses performed. Since it is unlikely that the natural flow of water through this environment was not altered in some fashion, it is concluded that natural variability and the effects of other anthropogenic alterations completely masked any changes in salinity and water temperature which may have arisen from LOOP activities.

RECOMMENDATIONS

Given the fact that we were unable to identify alterations to the temperature or salinity of the waters sampled (aside from the near bottom layer of abnormally high salinity associated with brine discharge), we assume that, in the absence of future construction, the role of hydrographic monitoring will be to provide a co-variate to be used in the analysis of biological data. A recurrent theme in the following recommendations is that monthly samples are too infrequent to properly define the sources of variability in redundancy. While it is impossible to estimate the effects of sampling less frequently than necessary at all stations, such effects are derivable for the stations with continuous recorders. For example, at station 317, 37% of the salinity variability in a nearly continuous 3.5 year subset of the record would not have been accurately represented by monthly sampling. Fewer samples, carefully situated in space, will allow improved resolution of the temporal variability, the means, and the variance structure. This, in turn, will allow better association of observed variations with their causes.

1. Offshore:

Two moorings should be maintained with continuously recording temperature and salinity sensors at near-surface and near-bottom depths. One should be near the offshore terminal and the other should be approximately mid-way to the coast. These should sample at hourly intervals to resolve tidal and lower frequency signals. All other stations should be discontinued.

The offshore region exhibited significant, spatially coherent trends in bottom salinity, bottom temperature and surface temperature. It is difficult to conceive of a process whereby LOOP operations could have been responsible for these trends. Furthermore, no BACI analyses indicated that LOOP operations had any negative effect on hydrographic properties in this region. Finally, it is difficult to attribute the thermal trends to atmospheric forcing since the scale of such forcing would require a similar (or enhanced) response in the shallow estuarine waters, a response which was not observed.

The most likely cause of the observed trends is intrusion of Loop Current rings, the lack of a signal in surface salinity being due to the higher natural variability in this signal. Unfortunately, we have not yet been able to identify an adequate time series of Loop Current ring paths with which to test this hypothesis. It should be mentioned that the time scale of this phenomenon is very long. Rings are shed approximately once per year and existing records (~20 years) are not yet long enough to define the low-frequency variability of the signal. Thus, any conclusions concerning trends which were influenced by this process must be tempered by the assumption that the record is too short to properly define a reliable trend.

The analysis of offshore data was hampered by samples which were clearly erroneous (probably instrument error) and a process which was undersampled, i.e. important, deterministic and stochastic variability in the measured parameters which occurred on time scales much shorter than the sampling period was not resolved. (Wind-driven and tidal variability has time scales shorter than one month.) On the other hand, the coherence length scales, distances over which the hydrographic properties varied in a coherent manner, for hydrographic parameters in this region are large, on the order of 10 to 20 km, at least. Mid-depth samples are not required, as the dominant stratification is defined by a strong halocline. Two stations located along a cross-shore transect will help define the large-scale mean spatial variability. Since the surface waters of this region are dominated by a river plume which is highly variable in space and time, additional moorings placed along isobaths would assist in defining the spatial patterns at any given instant in time. It is not clear that the added information provided by such moorings would warrant the cost of their deployment.

2. Nearshore:

Two moorings, oriented along a cross-shore line, should be maintained with continuously recording temperature and salinity sensors at near-surface and near-bottom depths. These should sample at hourly intervals to resolve tidal and lower frequency signals. All other stations should be discontinued.

The nearshore region exhibited no significant, spatially coherent temporal trends in either temperature or salinity. It is difficult to conceive of a process whereby LOOP operations could have been responsible for such trends, if they had been identified. Furthermore, no BACI analyses indicated that LOOP operations had any negative effect on hydrographic properties in this region. This is a region of strong cross-shelf gradients in properties, but smaller alongshelf gradients. Flow is strongly wind-driven and highly variable. Two moorings oriented cross-shelf will characterize the strong offshore gradients in water properties.

As an additional option, we suggest that two bottom-mounted acoustic Doppler current profilers which transmit data to shore in real time be deployed: one nearshore and one near the offshore terminal.

The current meter records from this region were too short and too intermittent to be of great use in characterizing the region. Acquisition of accurate current meter data from such environments is notoriously difficult. It is not clear, now that construction and brine pumping are completed, whether such data are warranted. In the event of a spill, though, this information would permit accurate tracking of the potential region of impact. If significant further brine discharge is anticipated, this information from a site near the diffuser would assist brine plume tracking (see below).

<u>**3. Lower estuary**</u>:

Assuming that the stations 315 and 317 will be continued as part of LDWF's long-term monitoring program for other purposes, similar instrumentation should be deployed at two other sites in the lower estuary, stations 322 and 7. Sampling should occur, at least hourly. Other stations should be discontinued.

The lower estuarine region exhibited no significant, spatially coherent trends in either temperature or salinity. Furthermore, no BACI analyses indicated that LOOP operations had any negative effect on hydrographic properties in this region. Spatial gradients are large in this region and time scales vary from the semi-diurnal to the interannual. Hourly recordings are necessary to adequately describe this variability, particularly in order to distinguish natural variability from possible LOOP-induced variability in case of events which impact the estuary. It is imperative that these stations be continued as proposed alterations in the amount of river water diverted from the Mississippi River to the Barataria Basin may invalidate all existing records as a basis against which to compare future potential impacts of LOOP activities.

A tide gauge should be deployed at the onshore storage site.

Water level is recorded by NOAA/NOS at Grand Isle. This identifies the apparent sea level rise at this location. It was unfortunate that a similar gauge was not deployed at LOOP facilities within the estuary (upper or lower) to identify possible construction-induced subsidence effects. While we are aware that a tide gauge was deployed in Little Lake and another south of the dome, we believe that these would have had to have been deployed within a few hundred meters or less of the construction in order to resolve the weak, but potentially important, signals expected from construction activity.

4. Upper estuary:

Stations 320, 324, and 12 should be continued and instrumented with hourly recording instruments similar to those recommended above. Other stations may be discontinued. An array of appropriate rainfall gauges would also be beneficial in helping to understand the salinity variability in the region.

The upper estuarine region exhibited no significant, spatially coherent trends in either temperature or salinity. Furthermore, no BACI analyses indicated that LOOP operations had any negative effect on hydrographic properties in this region.

Spatial gradients are important in this region and time scales of variability range, again, from the semi-diurnal to the interannual. Never-the-less, spatial scales are larger than the existing station spacing in some cases, providing unnecessary redundancy. Again, proposed river diversions to the basin obviate the use of the existing data sets as controls against which to test for future changes in characteristics or against which to identify the cause of alterations to the environment. The complexity of the region suggests that deployment of current monitoring stations would not be cost effective in this area. The upper estuary consists of a few large open water bodies connected by multiple channels, tidal creeks, and bayous. The cost of placing current meters in these channels in sufficient number to define the flow regime is prohibitive. Furthermore, it is not clear scientifically exciting information that would be derived from such an investment is necessary for the monitoring that LOOP is tasked to maintain.

5. Brine Monitoring:

In the event that significant brine monitoring should again take place, continuous recorders, deployed at increasing distances around the diffuser should be used to delineate the temporal and partially delineate the spatial variability of the plume size and the strength of its associated salinity anomaly. A minimum of six bottom temperature and salinity sensors should be deployed uniformly around the diffuser. (An additional six at a greater distance would enhance the program.) Adaptive sampling of a predetermined grid of stations is recommended for brine plume mapping, in preference to towing a sled. Information concerning the preferred direction of plume advance should be derived from continuous monitoring of near-bottom currents and radio telemetry of the data to the sampling boat, thus requiring deployment of an appropriate near-bottom current meter and telemetry package.

Plumes, both positively and negatively buoyant ones, are highly dynamic features. They respond to changes in sources strength and to ambient conditions of stratification, flow and mixing characteristics. Time scales on which these vary range from a few hours to seasons. Attempts to map the extent of a negatively buoyant plume must account for this space-time variability. The temporal variability can only be resolved through continuous monitoring. Records from the sled suggested that the sled structure may have been disturbing the interface between the brine plume and the ambient water. As an alternative, a salinity sensor could be carefully lowered to a specified distance above bottom at pre-specified grid stations. Stations could be added to or dropped from the sampling plan according to pre-decided criteria such as the absence of brine at two consecutive stations on a given transect. Continuous onboard monitoring of the shape of the brine patch using optimal interpolation and a laptop computer, or even hand contouring of the data, would allow stations to be added to the grid when the plume was observed to continue in a given direction. In order to understand the area of impact of the brine plume, such monitoring would need to include a variety of wind and stratification conditions and not be limited to fair-weather conditions.

6. General Discussion:

The potential remains that past or future LOOP activities could modify flow patterns, particularly within the estuarine reaches of the study area, to an extent that they impact the hydrography and, consequently, the biology. In fact, alterations of the flow regime could impact the biology without a concomitant change in temperature or salinity. It has been mentioned above, that the cost of maintaining a long-term current monitoring program adequate to define the flow regime of the estuary would be high. One might ask whether or not modeling protocols could be developed or applied which would resolve the potential effects of slow, long-term changes in the estuarine environment such as rerouting of flows. Models of this region have been developed and the potential exists for developing others. A major missing parameter is an accurate bathymetry of the region. Mixing coefficients (engineering parameters which describe the effects of small scale flow features not resolvable on the model grid), adequate forcing (wind fields, rainfall fields, water levels at the tidal passes), and sufficient computing power to run the models in a realistic time frame are presently not available. Progress in this field of research can and is being made. The models presently in existence, though, might be indicative of potential responses, not definitively predictive. If it is suspected that such slow, long-term changes might be occurring, additional monitoring and modeling efforts are advisable. It seems unlikely that such changes would be clearly detected with the program recommended above. This is designed to capture changes in the large scale hydrographic fields occurring on time scales of a few days to years.

ZOOPLANKTON AND ICHTHYOPLANKTON

by

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TASK 3: ZOOPLANKTON AND ICHTHYOPLANKTON

Significant and Non-Significant Results

Only a few statistical analyses had significant or marginally significant Direct LOOP Impact implications (DLI; Table 12), while another test had results which appeared to have Indirect LOOP Impacts (ILI; Table 12). Some test results appear to be related to oil discharge or spills and/or subsequent clean up activities while others to the construction phase. The discussion of marginally significant statistical results ($P \leq 0.1$) is environmentally and biologically important, because they clearly suggest that those parameters are sensitive to LOOP - related environmental perturbations.

The zooplankton biomass data set was by far the most complete (longest times series and largest sample size) and had a greater number of significant and/or marginally significant test results. The most relevant test finding resulted from the BACI Long-term, Inshore, Combined Impacts Model (2/78 to 12/95) which had the Clovelly oil spill data as a covariate. Oil as a covariate proved to be marginally significant ($P = 0.0983$) and showed an inverse (negative) relationship with zooplankton biomass (Table 5; Figure 5). Another relevant finding involving zooplankton biomass occurred within the DACI Inshore, Long-term Construction Impacts Model (Table 8) which had a marginally significant ($P = 0.0428$) During-After, Control-Impact interaction whereby mean zooplankton biomass at Impact stations was greater than the Controls (2.17 vs. 1.70 ml/m^3) During the construction phase, but was lower than Control estimates (1.40 vs. 1.81 ml/m^3) After construction. Perhaps construction disturbances, initially stimulated the standing stock of the zooplankton population which later was depressed by the long-term combination of perturbations. Other marginally significant test results were more difficult to explain in terms of Indirect LOOP Impacts, such as the During-After, Control-Impact interaction ($P = 0.0566$; Table 10) seen within the zooplankton biomass data in the DACI Brine Diffuser model run on the HL data set over the May 1980 to July 1986 time period. Mean zooplankton biomass at Impact stations was less than Controls within the During period, but was greater than Controls After (Figure 14).

The Osteichthyes Control-Impact interaction (Control mean densities greater than Impact) within the BACI Inshore Combined Impact Model (P = 0.0861; Table 5) was interesting, but had no additional impact support from the other interactions.

As with the oil, brine and construction analyses conducted inshore, the offshore LOOP Terminal Oil Impact analyses, which used the platform oil spill data set as a covariate, produced a number of significant and marginally significant temporal (in this case seasonal and annual) results (Table 11 and 12). However, two (2) test results relate directly to the discussion of LOOP-related environmental impacts. Densities for *Anchoa* spp., a very abundant coastal taxonomic group, displayed a marginally significant (P = 0.0991; Table 11; Figure 20) negative (inverse) relationship with oil spill data as a covariate. This negative relationship was not strong and appeared to be influenced by five large oil spill points. In addition, this negative relationship was not additionally supported by other significant Control-Impact (spatial) interactions, while there were significant temporal relationships found. The second noteworthy impact-related finding occurred with *Chloroscombrus chrysurus*, another very abundant coastal species. *Chloroscombrus chrysurus* displayed a marginally significant Control-Impact-Year Season interaction (P = 0.0271; Table 11; Figure 23). This statistical result was mostly a reflection of the mean density values for the control stations during the summer/fall time period in 1981 and 1985 being an order of magnitude greater than the impact station densities. Control station densities were also an order of magnitude greater than impact during the high abundance peak in the spring/summer period of 1982. Such a statistical finding may be indicative of environmental impact(s) associated with less clearly defined, spatial and temporal events such as relatively small, chronic oil spills.

In summary, the negative relationship between the Clovelly oil spill data and zooplankton biomass; and the zooplankton biomass During-After, Control-Impact interaction within the DACI Inshore Long-term Construction Model provide the clearest implications for

LOOP related impacts. In the coastal/offshore environment, there were two (2) indicators of potential environmental impact from LOOP-related activities. The Control-Impact, Offshore LOOP Terminal Oil Impact analysis of zooplankton and ichthyoplankton densities used platform oil spill data as a covariate, and season and year as main effects. The negative relationship between LOOP offshore terminal oil and *Anchoa* spp. densities and the Control-Impact-Year-Season interaction within the *Chloroscombrus chrysurus* analysis both indicate that these taxa are sensitive to LOOP-related environmental Impact. Clearly when the data sets were large, continuous or involved very abundant taxa, the analysis was sensitive enough to observe potential environmental impact(s).

The specific objectives of part one and two of Task 3 are to summarize all parameters tested which showed significant or noteworthy trends and those that were non-significant or unable to reject the null hypothesis of no difference (i.e., no change) for whatever reason (i.e., highly variable data, small sample sizes, low probability of likely Impact, etc.). Failure to detect an interaction in such statistical analyses can result either because the available data does not provide sufficient power to detect the Impact, or because there is no discernable Impact. A number of factors contribute to the lack of power in a statistical test. In environmental monitoring the reasons for low power are high variability, typical of the experimental material, and small sampling sizes. High variability cannot be controlled by the investigator, but is offset if sample sizes are made large by either intensive sampling or long-term sampling. The lack of a discernable impact can result because there is in fact no Impact. However, an actual impact may not be detected if the experimental design is inadequate. Some examples of design inadequacies are poor choices in control stations and failure to sample for seasonal differences.

Attributing causality to any of these significant analytical results goes far beyond the original scope, and sampling and statistical design of this study, and would necessitate extensive laboratory work, additional field work and probably carefully controlled in situ exposure of a wide variety of zooplankton and ichthyoplankton to brine, oil or construction/operational impacts. We have, however, inferred or offered likely or plausible explanations for statistical results. Table 12 summarizes the test results from all of the analyses conducted. Appendix Tables A-2 through A-7 provide the necessary monthly mean densities, standard deviations, and positive station sample sizes necessary for 95% confidence limits and coefficients of variation.

Sampling Program Recommendations

Environmental monitoring is intended to provide data for the detection of impact (should it occur) and to provide a baseline for restoration in the event of an impact. If one should occur, an impact may be associated with clearly defined temporal and spatial events, such as construction and post-construction stages. In this case the clearly defined periods can be tested as “before” and “after” categories which facilitates statistical testing. Impacts may also be associated with less clearly defined, temporal and spatial events such as relatively small, chronic oil spills. The gradual changes occasioned by this type of event are much more difficult to detect and require long, continuous periods of sampling to develop trend analyses. In the case of the LOOP project, the most important reason for monitoring is to provide a continuous baseline of the status of the environment as a precaution against a future catastrophic event. A continuous baseline of data preceding a catastrophic event is a necessary condition to determine impact and the measures necessary for mitigation and restoration. For example, continued environmental monitoring is necessary, because it has been predicted that: an average of between 3,740 and 5,400 barrels/yr would be spilled; that within a 24 year period there would be a single spill of at least 10,000 barrels of oil; and that a maximum credible spill of 240,000 barrels will occur once over a period greater than 50 years (DOT, USCG, 1976). While the LOOP record of accidental oil spills is below these prediction levels, the oil risk estimates point to the need for credible pre-spill baseline data. Furthermore, a number of our significant or marginally significant test results are explained by strong seasonality and abundance changes through time (Before-After or During-After interactions or Control-Impact-Year and Control-Impact-Year-Season interactions). The presence of such abundances trends only reinforce the dynamic nature of this unique and productive deltaic system and the need to continue to monitor and track how the ecosystem is changing/evolving through time. For example, if there is a decreasing abundance trend in species A and B, and in the year 2005 a post-oil-spill impact analysis is forced to use the

1978-1995 data set in a Before-After, Control-Impact design, that decreasing abundance trend, if it continued through time, could be erroneously attributed to subsequent LOOP-related activities.

In addition, the extent and importance (historically, culturally, and economically) of our renewable fisheries resources to Louisiana and the nation should not be underestimated or taken for granted if they are to be sustained. The coastal marshes of Louisiana are one of the most productive ecosystems in the world, supporting a wide variety of estuarine-dependent organisms. Louisiana leads fishery production within the northern Gulf of Mexico and is second only to Alaska among all states (NMFS 1997). Louisiana is the leader in the United States for the production of shrimp, blue crab, oyster, crawfish, tuna, red snapper, wild catfish, black drum, sea trout, and mullet (McKenzie et al. 1995). Ninety-five percent of the Louisiana fish and shellfish landings are estuarine-dependent species (McKenzie et al. 1995). The fish community of Barataria estuary is the most diverse of any estuary in Louisiana with 191 species from 68 families (Condrey et al. 1995).

Bearing in mind the responsibility above and the experience the last 18 years has brought, we make the following sampling program recommendations.

- We recommend reducing the number of sampling gears from 4 to 3, the number of sampling protocols from 6 to 3, and the total number of sampling stations from 97 (throughout history of study or from 19 - 21 in recent years) to a total of 14. The following monthly sampling stations should be maintained: pipeline and Clovelly impact stations 7, 15 and 38 and control 12, 13, 14 - all HL sampling stations; Diffuser impact station 36 and control 21 and 22 - all OM sampling stations, and LOOP Offshore Terminal impact stations 55 (OM) and 708 (BH) with controls 52 (OM) and 704 and 706 (BH). These stations have the strongest continuous data sets and are therefore in the best position to accomplish EMP Objectives 1 through 4. If the Diffuser brine pumping schedule is expected to remain at current low levels, then Diffuser sampling could possibly be discontinued, which would further lower the total number of stations sampled to 11.

- All station sampling should be replicated a minimum of 3-5 times so as to better estimate the within station variability and thereby increase the power and resolution of statistical analyses, which is in furtherance of EMP Objectives 2 and 3.

- Monthly samples should be collected each year (with extreme care taken toward ensuring long term preservation) but routinely worked up (taxonomically) every other year. Thus, complete sample sorting and identification of all larval fish (density, no./100m^3), zooplankton biomass (estimates from displacement volume methodology - ml/m^3), and the commercially - important decapods (i.e., *Penaeus* spp. and *Callinectes* spp. densities - no./m^3) and *Portunus* spp. would be available for an alternating year, time series (trend connection) going back to the present 18 year data set. At the same time the availability of archived samples would insure that at any given point in time, if there were to be a major oil spill, the subsequent BACI statistical analysis would have at least a two-year Before period of available samples. The BACI statistical design would also greatly benefit from the increased power that the station sample replication would bring to bear. This recommendation is in furtherance of all EMP Objectives.

- Supporting environmental data are needed to supplement/complement the zooplankton and ichthyoplankton sampling program. Monthly water column profiles at each station for temperature, salinity, conductivity, turbidity, dissolved oxygen, and surface estimates for chlorophyll are needed. In addition, brine and oil spill data for inshore (Clovelly) and offshore LOOP Diffuser and Terminal sites are needed for future analyses as covariates. Recommendation is in furtherance of EMP Objectives 1 through 4.

- Moored current meter arrays around the LOOP offshore terminal are needed to guide adaptive zooplankton and ichthyoplankton sampling responses to predicted major offshore oil spills. This recommendation is in furtherance of EMP Objective 3.

- Resource managers need to formulate a specific oil spill response plan for the LOOP Offshore Terminal that would include sampling at the long-term monitoring stations in that area at an increased frequency and with additional replication (EMP Objective 2).

- Any new construction or planned discharge scenario should have an adequate Before sampling data collection period (2-3 years of pre-Impact data collection) in furtherance of EMP Objectives 1 through 4.

NEKTON

by

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DEMERSAL NEKTON

The Louisiana Offshore Oil Port (LOOP LLC.) is licensed under the federal Deepwater Ports Act (33 U.S.C. 1501, *et seq.*) and the Louisiana Offshore Terminal Act (LA R.S. 34:3101 *et seq.*) to construct and operate facilities in coastal Louisiana for off-loading oil tankers, transporting oil ashore through pipelines, and temporarily storing oil before ultimate shipment to refining centers located nationwide. Both the state and federal licenses required environmental monitoring of LOOP construction and operational activities. As part of the Environmental Monitoring Plan, demersal nekton (i.e., bottom oriented fishes and large invertebrates that are active swimmers but susceptible to trawl capture) were sampled at monthly intervals at several stations along the LOOP pipeline and in adjacent areas. This chapter meets the requirements defined in Task 3 of the data analysis of the LOOP marine and estuarine monitoring program for 1978 to 1995.

Significant Results

We detected several significant construction-related trends in nekton species and size class abundances in the BACI analysis. Summaries of 11 LOOP impact findings for species and size classes with significant (MIXED, $p < 0.05$, Dunn-Šidák adjustment) interaction terms indicate that LOOP construction influenced the CPUE of important nekton species. An additional 13 temporal or spatial effects (i.e., main effects) associated with impacts (i.e., interactions) were also detected. Significant interactions (LSMeans, $p < 0.05$, Tukey-Kramer adjustment) that imply LOOP impacts, the significant effects (i.e., spatial, temporal, or interaction), the trend direction, if any, and probable causes of the observed effects are indicated:

Station[a]	Species	Size Class (mm)	Significant Effect	Trend	Cause of Difference
Station 31					
	Lesser blue crab	< 15	Temporal	Increase	LOOP construction
			Interaction	Increase	LOOP construction
	Southern kingfish	30 to 100	Temporal	Decrease	LOOP turbidity increase
			Spatial	High at impact	Non-LOOP
			Interaction	Decrease	LOOP turbidity increase

Station 33				
Lesser blue crab	< 15	Temporal	Increase *	Non-LOOP
		Interaction	Decrease *	LOOP construction
Bay whiff	≥ 100	Temporal	Decrease *	LOOP construction
		Interaction	Decrease *	LOOP construction
Mantis shrimp	≥ 100	Temporal	Decrease *	Non-LOOP
		Interaction	No trend *	Non-LOOP
Spotted seatrout	30 to 100	Temporal	Decrease *	LOOP construction
		Interaction	Decrease *	LOOP construction
Spotted seatrout	All sizes	Temporal	Decrease *	LOOP construction
		Interaction	Decrease *	LOOP construction
Station 36				
Southern flounder	≥ 100	Temporal	Decrease *	LOOP turbidity increase
		Interaction	Decrease *	LOOP turbidity increase
Southern flounder	All sizes	Temporal	Decrease *	LOOP turbidity increase
		Interaction	Decrease *	LOOP turbidity increase
Station 53				
Atl. brief squid	≥ 100	Temporal	Decrease *	LOOP construction
		Spatial	High at impact	LOOP construction
		Interaction	Decrease *	LOOP construction
Station 54				
Atl. brief squid	≥ 100	Spatial	High at impact	LOOP construction
		Interaction	Decrease *	LOOP construction

[a] Impact station compared to appropriate control station(s).
* Species estimates were not available for the before-construction phase, so trends refer to the after-construction and during-construction phases.

We also detected significant (MIXED, $p < 0.05$, Dunn-Šidák adjustment) LOOP-related influences of brine discharge at the brine diffuser (Station 36_I) on size classes of two species, Gulf menhaden and southern flounder. Both impacts were also associated with significant downward temporal trends. Significant interactions (LSMeans, $p < 0.05$, Tukey-Kramer adjustment) that imply LOOP impacts, the significant effects (i.e., spatial, temporal, or interaction), the trend direction, if any, and probable causes of the observed effects are indicated:

Species	Size Class	Significant Effect	Trend	Cause of Difference
Gulf menhaden	$30 \leq x < 100$ mm	Temporal	Decrease	LOOP turbidity increase
		Interaction	Decrease	LOOP turbidity increase
Southern flounder	≥ 100 mm *	Temporal	Decrease	LOOP turbidity increase
		Interaction	Decrease	LOOP turbidity increase

* The only individuals collected were in the size class ≥ 100 mm; therefore, the comparisons for southern flounder species were identical.

LOOP-Independent Results

We detected significant construction-related temporal trends for 11 size classes of seven species that did not have significant interaction terms (i.e., LOOP-related impacts were not detected). Although these trends could not be attributed directly to LOOP construction, they indicate the dynamic nature of marine and estuarine nekton populations:

Station[a]	Species	Size Class (mm)	Trend
Station 22			
	Blue crab	15 to 30	High during
	Pink shrimp	30 to 100	High during
Station 33			
	Spot	≥ 100	Decrease *
	Atlantic brief squid	30 to 100	Decrease *
	Mantis shrimp	30 to 100	Decrease *
		All sizes	Decrease *
Station 36			
	Blue crab	15 to 30	Decrease *
		30 to 100	Decrease *
		All sizes	Decrease *
Station 53			
	Gulf butterfish	30 to 100	Increase *
Station 54			
	Iridescent swimming crab	All sizes	Increase *
		30 to 100	Increase *

[a] Impact station compared to appropriate control station(s).
* Species estimates were not available for the before-construction phase, so trends refer to the after-construction and during-construction phases.

We also detected significant brine discharge-related temporal trends at the brine diffuser station (Station 36_I) for nine size classes of five species that did not have significant interaction terms:

Species	Size Class (mm)	Trend
Sand seatrout	$30 \leq x < 100$	Decrease
	≥ 100	Decrease
	All sizes	Decrease
Silver seatrout	$30 \leq x < 100$	Increase
	All sizes	Increase
Southern kingfish	$30 \leq x < 100$	Increase
	All sizes	Increase
Spot	$30 \leq x < 100$	Decrease
Star drum	≥ 100	Decrease

In the analyses of three oil spill events at the offshore oil port, we did not detect any significant interactions for any of the size classes of the 37 species analyzed. Nevertheless, we did detect significant temporal trends for 11 size classes of six species:

Spill Date & Amount	Species	Size Class (mm)	Trend
2-April-1983 16,758 gal.	Longfin squid	$30 \leq x < 100$	Increase
	Lesser rock shrimp	$30 \leq x < 100$	Increase
		All sizes	Increase
21-October-1985 21,000 gal.	Longfin squid	$30 \leq x < 100$	Increase
	Bighead searobin	≥ 100	Decrease
		All sizes	Decrease
April-1990 (combined) 102,226 gal.	Bigeye searobin	≥ 100	Increase
		All sizes	Increase
	Atlantic brief squid	$15 \leq x < 30$	Increase
		≥ 100	Decrease
	Rough scad	$30 \leq x < 100$	Decrease
	Longfin squid	≥ 100	Decrease

No significant LOOP-related spatial, temporal, or interaction effects on community descriptors (i.e., species diversity, richness, and evenness, total individuals, total fishes, total invertebrates, total decapods, and contribution of rare species) were detected for the construction or operation phases, and we did not detect significant effects for the majority of the size classes or species. Nevertheless, this does not necessarily lead to the conclusion that LOOP-related construction, brine discharges, and/or oil spills were benign. While the impact events may not have been demonstrated to be biologically significant for many nekton species, a variety of factors could reduce the sensitivity of BACI analyses to detect significant events, including inadequate number of spatial or temporal samples to test a particular impact, the absence of appropriate impact and control stations, discontinuity in the monthly sampling at some stations, and the possibility of a LOOP-related influence on a scale large enough to include the designated control stations. Thus failures to reject the null hypothesis in most instances, tested on most species and size classes, do not mean that the null hypothesis was correct.

Given that the original objectives of the LOOP Environmental Monitoring Plan are still relevant, it is vital to continue to monitor for LOOP-related impacts on the nekton community, species, and size classes. The existence of significant temporal and spatial trends and our finding 13 impacts provide further justification for continuing to monitor LOOP activities, because the baseline for future comparisons must be current for reliable analyses. Continued sampling will reduce the variability in the data, resulting in a more robust assessment of future potential impact events, and reliance on the existing baseline is not a tenable option because the baseline is shifting (i.e., many significant temporal and spatial trends were detected).

Recommendations

We have identified possible improvements to the sampling program that relate to temporal and spatial patterns of sampling, sample replication, and the number of environmental variables measured in conjunction with demersal nekton trawls.

- **The monitoring of nekton associated with the LOOP pipeline should be continued on a monthly basis each year, with increased replication in the event of a potential impact.**

Environmental monitoring is intended to provide data for the detection of impacts, and to provide a baseline for restoration in the event of an impact. A potential impact event may be associated with clearly defined temporal and spatial events, such as construction and post-construction phases. In this case the clearly defined periods can be tested as "before" and "after," which facilitates statistical testing. Impacts may also be associated with less clearly defined temporal and spatial events such as relatively small, chronic spills. The gradual changes occasioned by this type of event are much more difficult to detect and require long, continuous periods of sampling to develop trend analyses. In the case of the LOOP project, the most important reason for monitoring is to provide a continuous baseline of the status of the environment to meet all four of the objectives of the Environmental Monitoring Plan. A continuous baseline of data preceding a biologically significant, but non-catastrophic event will be necessary to determine the impact of the event and the measures necessary for mitigation and restoration.

Continuing the nekton sampling protocol is also vital for understanding the influences of LOOP-related activities. The Gulf coastal waters are biologically dynamic. We detected significant temporal trends for 21 size classes of 17 species that did not detectably result from LOOP-related activities. This suggests that species abundances are changing over time. As the baseline shifts, continued monitoring is needed to maintain the validity of the pre-impact data base in the event of a future LOOP impact. To ensure an accurate assessment of potential impacts, data reflecting current conditions are required. Many of the stations were discontinued in the early 1980's. For example, sampling at Stations 17_C and 19_I was discontinued in January 1982, and the data collected from those stations are now outdated because of changing temporal and spatial patterns of nekton distribution and abundance. While appropriate to assess influences related to the initial LOOP construction phase, the now terminated data sets are inadequate to provide a baseline for future potential impacts. Old data probably will not provide convincing results in a changing baseline situation. Testing the effects of future impacts against data over a decade old will reduce the accuracy of the analyses, and will cast considerable doubt on the conclusions.

The present level of monthly sampling seems adequate for maintaining a robust baseline, but resource managers should consider a response plan to increase the frequency of sampling in the event of a major, but non-catastrophic, impact (e.g., a moderate to major oil spill) for more statistical sensitivity. In order to conduct a powerful BACI analysis with a chance of detecting a 50 % change in CPUE of a typical species, three years of post-impact data would be compared to the preceding nine years of data. This requires continuous, long-term baseline data at control and impact stations. Under the current sampling intensity, the three years after a potential impact event at the offshore port would only generate 144 samples with 2 control and 2 impact stations (currently there are one control and three impact stations, but see recommendations for the Offshore Port below). To evaluate changes in sensitivity with increased sampling frequency in a response plan, we used Atlantic brief squid ($\geq$ 100mm), a common species at the offshore port stations, which had a marginally significant interaction term ($p > 0.067$). The current data set with 220 samples was sufficient to detect a CPUE difference of about 85 % between control and impact stations before and after a moderate oil spill (21-October-1985). To detect a 50 % change in the CPUE of Atlantic brief squid CPUE the sample size would have to be about 430. Because of the transient nature of most impacts, a three year time frame for impact assessment should be used for planning. By sampling three times per month at four stations for three years, 432 samples can be collected. Alternatively, with only one sample per station per month, either nine years of data would be needed, which would be insensitive to short-term effects, or three times the number of impact and control stations would be required.

- **If additional major construction is proposed, sampling at appropriate impact stations and control stations should be conducted for at least two years, twice monthly, to ensure adequate before-construction data for impact analysis (higher sampling rates over one year would be a less powerful alternative).**

The lack of adequate pre-construction estimates of species abundances at many of the impact stations limited the utility of the BACI analyses. Pre-construction estimates are vital to the BACI analysis because the pre-impact measurements are used as a reference for subsequent comparisons. The estimates from the control stations do not always adequately represent conditions at the impact stations prior to the impact. Without an adequate pre-impact estimate, a convincing assessment of the observed differences at the impact station may not be possible. The purpose of the BACI analysis is to test for impacts that are demonstrated by a change at the impact station that does not correspond to changes at the control stations. For example, a convincing assessment of a positive or negative impact on southern kingfish can be made at Station 31_I, because the before-construction phase was adequately characterized. Southern kingfish between 30 and 100 mm were significantly more abundant at Station 31_I than at the control stations prior to construction, but significantly less abundant during and after construction. This interaction between the temporal and spatial effects indicates a negative impact due to construction. In contrast, at Station 33_I, the lack of adequate sampling before construction precluded accurate impact assessment on spotted seatrout which were significantly more abundant during and after construction at Station 33_I than at the control stations (see Table 9 in Task 2 report). If the mean CPUE at Station 33_I before construction was near zero, as it was at the control stations, then LOOP construction would have been interpreted as having had a net positive influence on spotted seatrout. Moreover, if the mean CPUE at Station 33_I was near 49 individuals per hour before construction, as it was during construction, then spotted seatrout would have decreased in the post-construction phase (a negative influence). Without the pre-construction estimate, we can only deduce that spotted seatrout mean CPUE decreased after construction relative to during construction. The recommended two-year bimonthly sampling protocol will provide 48 seasonally balanced samples at each station, which should provide adequate data for a more robust analysis of the influence of the new construction.

- **Control stations without appropriate impact station pairings should be discontinued, unless these stations are necessary for the evaluation of impacts related to variables in other datasets (e.g., Plankton, Water Chemistry, etc.)**

Several nekton stations in the sampling design could not be incorporated into the analyses. Stations 1_C, 4_C, 37_C, 41_C, and 42_C were not similar enough to any other stations to be grouped, and were excluded from the BACI analysis. Serious consideration should be given to dropping these stations for nekton sampling and other monitoring components if no valid reason can be identified for retaining them. Alternatively, they may be grouped with new impact stations to provide a more robust baseline for the control stations in an impact assessment.

- **Additional impact and control stations are necessary inshore of Station 7_I.**

Currently, coverage along the pipeline north of Station 7_I is nonexistent. Only one impact station, Station 19_I, existed inshore from Station 7_I, and it was discontinued in 1982. This arrangement leaves over 30 km of the LOOP pipeline, as well as the entire LOCAP pipeline, unmonitored. Since this area of the pipeline is unmonitored for nekton, no impact assessment of a potential pipeline failure or oil spill along the corridor could be made. Coverage at locations where the pipeline crosses a lake or major bayou is essential to provide adequate data for impact assessment. Specifically, impact and control stations should be established in the canal system surrounding the Clovelly Dome Terminal. This terminal was the site of recurring minor and moderate oil spills, but these could not be assessed because no nekton samples were collected from the area. If a large spill were to occur, no baseline data would be available for impact assessment. Consideration should also be given to adding two impact and four control stations in the middle and inshore zones where coverage is currently scant. Perhaps sampling could be restarted at Station 15_I as an impact station, with Station 14_C as its control, or Stations 1_C and 41_C could be paired with Station 38_I at the freshwater intake for the Clovelly Dome Terminal.

- **An additional control station is required in conjunction with the Offshore Oil Port, and one of the impact stations could probably be dropped.**

Only one control station (Station 52_C) exists for the three monitored Offshore Platform stations (Stations 53_I, 54_I, and 55_I). Because this control station is east of the pipeline, an additional station should be established west of the pipeline. The Gulf coastal waters have large-scale gradients related, in part, to the Mississippi River plume. A single control station cannot adequately account for these gradients, whereas two stations, straddling the pipeline, could. It is necessary to account for the influence of these gradients on nekton so that an observed difference between the control and impact stations will not wrongfully be attributed to LOOP activities. If necessary, station 55_I could be dropped, because of its proximity to Station 53_I, and because it has the least complete data.

- **Assignment of control stations to impact stations for comparisons should be made *a priori*, if possible.**

Significant differences in environmental conditions between control and impact stations in all three zones were detected for depth, but these differences were probably due to the lack of an *a priori* selection of stations as control or impact for this analysis. Choosing stations based on environmental similarity "after the fact" reduces the likelihood of finding a LOOP-related impact because we are restricted to trying to detect differences between the most similar stations. If the observed environmental similarity used to group stations was enhanced by LOOP, the species and community differences will be minimal. Association of control and impact stations should have been made *a priori* or at least based on pre-construction data analysis; however, the lack of adequate pre-construction sampling did not permit this designation method. This problem should be addressed in the establishment of future stations, but the *a posteriori* association has the effect of making our current identification of LOOP impacts more conservative in favor of LOOP.

- **Monitoring of the current environmental variables, species, and sizes, used in the nekton data analyses should continue.**

The list of environmental variables measured with nekton samples, including water temperature, salinity, dissolved oxygen, turbidity, depth, and chlorophyll *a* should be continued, and not reduced, with continued monitoring. The identification of species should be continued and improved in the case of important species (i.e., anchovy species, roughneck shrimp species, and tonguefish species). During continued monitoring, the lengths (sizes) of individuals should continue to be measured at 1 mm intervals, as initiated in January 1992, and weights should continue to be measured in grams.

SEDIMENT QUALITY

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SEDIMENT QUALITY COMPONENT

Significant Results

Table 1. Significant temporal results from Task 2 Data Analyses.

Variable of interest	Temporal trends	Covariables	Significant Impacts
Light oil, Clovelly storage facility	Increased levels		Possible, but for early years only
Light oil, offshore pumping station	Increased levels		Possible, but for early years only

Table 2. Significant spatial results from Task 2 Data Analyses.

Variable of interest	Spatial trends	Covariables	Significant Impacts
Total PAHs, LOOP Diesel Dock	Increased levels		Boat servicing activity, but likely non-LOOP activity is contributor
Total PAHs & heavy oil in canals around Clovelly	Increased levels		A few of eight stations may be elevated, again, non-LOOP boating activities may be the significant contributing factor
Light oil, Clovelly storage facility	Increased levels		Possible short-term conditions, not apparent last 10 years
Heavy oil, offshore pumping station,	Increased levels		Possible short-term condition, not apparent last 10 years

The above spatial and temporal trends include statistically significant findings with the light oil and heavy oil components for petroleum hydrocarbons measured during the early years (1979 through

1984). For reasons explained in the Phase II report, findings reported for the PAH component of petroleum hydrocarbons measured during the last 10 years (1985 through 1995) are believed to be more reliable.

Non-Significant Results

There is only weak evidence that LOOP related spills contributed to increased petroleum hydrocarbons in the stations representing the Clovelly storage facility, sediments in canals connecting with the Clovelly facility, and at the offshore pumping facility. Statistically significant differences seen for these were associated with the data generated during the early years which may be less reliable than the data generated during the later years.

Though statistically significant increases in PAHs were found in the Clovelly area at a few stations in connecting canals, and in the LOOP Diesel Dock area, these findings should be considered "insignificant" or at least not a clear implication of LOOP impacts because of the likely contribution of non-LOOP boating and perhaps non-LOOP petroleum activity in these areas. In the "Clovelly area" grouping, only two or three stations out of about eight likely contributed to the significant increased PAH levels, but these are in public waterways and not necessarily the closest stations to the Clovelly storage facility. Similarly, a small proportion to a large proportion of the source of significantly elevated PAH levels at the LOOP Diesel Dock area could have been due to other boating activity in the immediate area. It is not possible to attribute the findings at this site entirely to LOOP.

The reasons for the non-significant finding of brine water release on pore water salinity at the Brine Diffuser Outlet stations is due entirely to a very small, non-significant change in pore water salinity at this site relative to the control station. The salinity values for both sets of stations were very consistent over time (not nearly as variable as petroleum hydrocarbon content) and essentially the same level. Thus there was just no salinity impact at these outlet stations.

Recommendations

The recommendations below are primarily designed to reduce the cost of monitoring while retaining the ability to assess the degree and areal extent of contamination should a major spill associated with LOOP activities occur.

-- **Reduce sampling frequency for sediment quality monitoring to once a year.** PAHs degrade slowly in sediments, but, they are relatively persistent and significant impacts due to a spill should be evident for many months to many years, depending on the magnitude of contamination. If a spill results in a measurable impact in terms of PAH levels that can be detected for only less than a year, it is likely not an ecologically significant impact. Of course, if a major spill occurs, then sampling should be done soon and more frequently than annually. But, for baseline monitoring where spills are not known to have occurred, annual measurements of sediment PAH levels should be sufficient.

-- **Eliminate all on-shore stations intended to be controls if the Louisiana Oil Spill Coordinator's Office completes an on-going 3-year baseline monitoring study.** This study is measuring more than 65 different petroleum hydrocarbon compounds in marsh soils and sediments at approximately 1,000 coastal sites, and, LOOP areas are well represented. The analytical protocol and quality control procedures are very exacting and the data being generated are supposed to be reviewed by an expert before they are accepted. If a LOOP related spill should occur, then at the same time impacted areas are being sampled, of course LOOP control sites (selected ones used in this project) should be sampled at the same time for comparison to the impact site data.

-- **Add at least two more stations near the LOOP offshore facility.** Currently, there is only one station very near the center of the ship unloading facility. Depending on wind and current direction at the time of a spill, the one station could easily miss an impact as spilled oil may move in a direction away from any single monitoring station.

-- **Retain measurements for the usually measured 10 to 15 primary polynuclear aromatic hydrocarbons, (naphthalene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzanthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indenopyrene, dibenz(a,h)anthracene, benzo(g,h)perylene, and total parent PAH compounds) sand and clay content, organic matter content, bottom and pore water salinity, and sediment moisture content.** LOOP now has 10 years of good data on the PAH compounds. The PAH compounds and the other parameters mentioned are the important parameters associated with an oil spill, or likely important covariables, and will provide data that will help interpret sediment PAH levels.

-- **Eliminate most other measurements not listed above unless they are needed for evaluating impacts on benthic organisms.** For the purpose of evaluating PAH data needed to determine the impact of an oil spill, most other measurements, including the alkylated PAH compounds, chloride, metals, chemical oxygen demand, Kjeldahl nitrogen, phosphorous, pH, and sulfide, are not essential.

-- **Consider adding sampling for measuring the sedimentation rate near the offshore pumping facility and at stations along the pipeline.** There may be substantial sedimentation occurring in some of these areas which would be important should a spill occur in planning sampling depths for monitoring purposes and considering natural burial rates of petroleum hydrocarbons from a spill that becomes associated with the sediment surface.

-- **Consider up to 3 separate subsamples for each station sampled where subsamples are collected something like 50 meters apart.** This change would allow evaluation of the within-sample variability, increasing the power of the statistical models to detect between-sample differences.

-- **In future sampling in open waters, use modern differential GPS instrumentation to more precisely locate sampling stations and to facilitate returning to the same sampling location.** This should reduce variability associated with sampling.